News & Views

Origin of the Yellow Sea — An insight

Yaoling Niu [1,2,3,*] · Jie Tang [1,4]

1 Department of Earth Sciences, Durham University, Durham DH1 3LE, UK
2 Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China
3 Qingdao National Laboratory for Marine Science and Technology (Marine Geology), Qingdao 266061, China
4 College of Earth Sciences, Jilin University, Changchun 130061, China

*Correspondence: Professor Yaoling Niu (yaoling.niu@foxmail.com)

Niu et al [1] recently show that the basement of the Chinese continental shelf (beneath East China Sea and South China Sea) is geologically unrelated to the continental lithosphere of eastern China, but is of exotic origin. This alien/exotic terrane of a sizeable mass with large compositional buoyancy (either an oceanic plateau or a micro continent) was transported along with the Pacific plate that spread in the course of NW direction and subducted beneath the eastern margin of the continental China in the Mesozoic. Collision of this buoyant and unsubductable alien terrane with the continental China jammed the trench and terminated the subduction at ~ 100 Ma. This conclusion comes from a detailed analysis of the distribution of Jurassic-Cretaceous granitoids (~ 190 Ma to ~ 90 Ma) throughout the entire eastern continental China in space and time. The termination of the granitoid magmatism at ~ 90 Ma signifies subduction cessation at this time or shortly beforehand, e.g. at ~ 100 Ma. The jammed trench is predicted to locate on the Chinese continental shelf in the vicinity of, and parallel to, the Southeast coastal line, whose curved arc-shape is actually inherited from the pre-100 Ma arc-shaped trench. To locate this Mesozoic plate boundary to the north in the Yellow Sea region and beyond is not straightforward because of the more recent (< 30 Ma) tectonic re-organization associated with the opening of the Sea of Japan. The latest finding of the younger granitoids (as young as ~ 56 Ma) in the Russian Far East by Tang et al. [2], together with the presence of younger granitoids in South Korea and Southwest Japan (as young as 71 Ma) (Fig. 1a), presents us an impetus for addressing some unanswered questions of [1] and also offers insights into the tectonic evolution of the region, including the nature and origin of the Yellow Sea:

> *The Yellow Sea is a continent-rifted basin with buried basaltic seafloor basement although the said seafloor spreading must have ceased for some time.*

This apparently brave hypothesis is unfamiliar to the community and differs from some long-held interpretations and popular perceptions, but it is the result of observation-based reasoning and logical analysis, which deserves serious consideration. The purpose of this *News and Views* paper is to encourage the community to discuss and debate on this important problem towards the genuine understanding of the tectonic evolution of the region in a global context.

Despite the effort over the years [3-5], plate tectonics reconstruction in the broad northwestern Pacific region remains largely speculative and unconstrained [1]. For example, geological and geophysical data indicate that the landmass of Japanese islands was separated from the eastern margin of the Eurasian continent in response to the backarc basin (the Sea of Japan) opening in the time frame of ~ 30 to 15 Ma [3,4], but this and other landmasses of the greater region had been in the same relative positions with the same geometries as they are at present in global reconstruction models although backarc spreading histories are indicated [5]. The most intriguing question in the context of the geological evolution of eastern China since the Mesozoic concerns the nature and origin of the Yellow Sea [1]. In this communication, we briefly discuss our view on the geological origin of the Yellow Sea, which is unfamiliar to many, but is a logical and testable hypothesis thanks to the finding of younger granitoids in the Russian Far East [2]. We discuss the reasoning towards the hypothesis and suggest ways with which to test the hypothesis.

Observations and reasoning towards the continental rift origin of the Yellow sea

The basement of the Chinese continental shelf beneath East China Sea and South China sea can be logically explained as being an alien terrane that collided with the southeastern margin of the continental China at ~ 100 Ma [1] (Fig. 1a). However, this alien origin does not apply to the adjacent Yellow Sea basement to the north because the latter is, strictly speaking, not a continental shelf, but "*seafloor of an intra-continental basin*" precisely located between the North China Craton (NCC) with Precambrian basement and the Korean Peninsula with comparable Precambrian basement [6]. The NCC has also been known as Sino-Korean para-platform for many decades [see 6], pointing to the well-understood geological connection between the two. Indeed, recent studies have demonstrated in greater detail the terrane and lithological correlations between the continental China and the Korean Peninsula [6-11], especially the correlation of the ~ 230 Ma eclogite of the Gyeonggi Massif in South Korea with the Dabie-Sulu Orogenic Belt in eastern China (Fig. 1b), which, to a first order, signifies the geological expressions of North and South China on the Korean Peninsula [7-11].

The intriguing, yet unanswered or even hardly asked, question is why the Korean Peninsula and eastern China should share the same or comparable pre-Cenozoic geology. Zhao et al. [11] used the paleomagnetic data analysis to confirm the traditional view that the NCC and the Korean Peninsula have been a single coherent block since the early Paleozoic, i.e., the known Sino-Korean para-platform perception, without mentioning why the Yellow Sea should have been there as it is at present. Hao et al. [12] nicely summarized the existing work and used a combined method of seismic tomography and gravity data to infer the existence of some structural features in the Yellow Sea crust that may help explain the connection of the Korean Peninsula with eastern China. However, it is perplexing to have the lithospheric mass of the Yellow Sea size simply missing or born to be absent in the otherwise coherent Sino-Korean para-platform. The lesson that we have learnt from the development of the continental drift hypothesis reminds us that the two landmasses on both sides of the Yellow Sea basin must have once connected even though it is no longer the case at present. It follows that the Yellow Sea basin must have been developed through continental rifting to rift opening and to seafloor spreading. Indeed, the similar shape of portions of the costal lines on both sides of the Yellow Sea is indicative. This reasoning leads to the prediction that the Yellow Sea must be floored, at least partially, with basaltic crust resulting from seafloor-spreading induced mantle upwelling and decompression melting [13]. This is logical because with a separation distance in excess of 600 km (width of the Yellow Sea) in places, lithosphere stretching, thinning and breakup must be complete as evidenced by the seafloor spreading and magmatism of the Red Sea, which is on average < 300 km wide.

The above reasoning is reinforced by the finding of the younger granitoids in the Russian Far East, South Korea and Southwest Japan (see [2]). As above, Niu et al. [1] concluded that the collision of an alien terrane carried by the paleo-Pacific plate with the eastern continental China at ~ 100 Ma jammed the trench and accreted the basement of the Chinese continental shelf (beneath East and South China Seas), resulting in a new plate boundary to the east between the newly accreted Chinese continental shelf and the paleo-Pacific plate (also see [2]]. The lack of granitoids of < ~ 90 Ma in the eastern continental China and the greater Chinese continental shelf region is consistent with the new plate boundary being of transform nature with the paleo-Pacific plate, whose course of spreading changed from the prior NW direction to NNW (i.e., similar to the age-progressive Emperor Seamount Chain of Hawaiian hotspot origin) because of the trench jam and Pacific plate rotation [1]. At this time (< ~ 90 Ma), the northeastern margin of the Eurasian continent (Korea, Japan and Russian Far East) is expected to be in transpressional contact with the NNW moving Pacific plate and the anticipated oblique subduction continued to produce granitoid magmatism despite being less voluminous [2]. This requires that the landmasses of Japanese islands and the Korean Peninsula locate at the active margin of the Eurasian continent as does the Russian Far East. This also requires the absence of the Bohai Sea and Yellow Sea at this time and throughout the Mesozoic because no granitoids are younger than 100 Ma along the coast of the Shandong Peninsula and around the Bohai Sea [1].

Therefore, with all the observations considered, we cannot avoid the conclusion that the Yellow Sea is a Cenozoic continent-rifted basin most likely floored with basaltic crust produced as the result of seafloor spreading induced mantle upwelling and decompression melting. The inlet Bohai Sea is part of the same Yellow Sea system, but its modern geological expression is largely controlled by the Tan-Lu Fault system (Fig. 1b). The Yellow Sea, excluding the Bohai, is ~ 960 km from north to south and ~ 700 km from east to west with an area of 380,000 km^2. Its average shallow depth of ~ 44 m at present is consistent with its golden yellow color, which gives the name of Yellow Sea because of constant and volumetrically significant sediment (sands, silts and muds) input from the Yellow River (minor from the Haihe River and little from the Liao and Yalu rivers). We can also predict that there must be continued seabed substance because of the constant addition of the sediment loading.

Testing the hypothesis of the continental rift origin of the Yellow Sea

The above conclusion is in nature a testable hypothesis. The significance of testing this hypothesis cannot be overemphasized in order to correctly understand the geological interactions between the Eurasian continent and the Pacific plate (a general term used here without specifying Izanagi, paleo-Pacific, present-day Pacific and Philippine plates) subduction since the Mesozoic in the context of global plate tectonics reconstruction. We suggest ways of testing the hypothesis by considering the following:

1. The match of the coastal lines on both sides of the Yellow Sea is indicative, but is not perfect. We suggest that an improved match can be obtained at a deeper level, perhaps > 100 m below the sea level because of the more recent surface and near surface coastal modifications. This can be done through coastal region seismic stratigraphic/lithological analysis because of the thick sediments and on average shallow seabed of ~ 40 m.
2. Fragments of pre-Mesozoic crustal materials could be found in the Yellow Sea basement, but we predict that such materials are rare and generally absent especially in the far interiors of the basin ~ 200 km away from the coastal lines. This can be tested with well-designed seismic experiments along several latitude-parallel traverses [15].
3. The seafloor spreading of the Yellow Sea must have stopped for some time, but the basaltic crust must be preserved and the locus of the spreading center can be predicted to locate at the “middle” of the basin as indicated (Fig. 1b) because it is a thermal (seafloor cooling) requirement. This can be tested by integrated seismic and gravity studies as done in the literature [14,15]. The success is expected if the experiments are well designed to effectively test the hypothesis because seismic and gravity data are distinctly different between basaltic rocks and sediments/sedimentary rocks.

4. It follows from 2 and 3 above that the lithosphere (crust and mantle lithosphere) beneath the Yellow Sea is thin and the asthenosphere is shallower than beneath the adjacent landmasses. This prediction is in fact already verified by the positive Bouguer anomaly with values as much as 42 mGal beneath the Yellow Sea [12]. Further high resolution gravity experiments are needed to reveal the fine structures beneath the greater region.
5. The opening of the Yellow Sea basin is predicted to begin from south and propagate northward before cessation of the seafloor spreading. This implies that the Korean Peninsula underwent counter-clock wise rotation with respect to eastern China (not absolute rotation with respect to Earth's magnetic field; Fig. 1b). To test this is not straightforward because the most convincing method would be to obtain magnetic age stripe patterns of the basaltic seafloor, but such data are unavailable and hard to acquire. Lacking such magnetic data is also the very hindrance for better understanding the opening history of the Sea of Japan although basaltic rocks of ocean ridge basaltic compositions have been sampled by the Ocean Drilling Program (ODP). In this case, an integrated study of petrology, geochronology and magnetism on Cenozoic rocks from the Korean Peninsula and land masses in the greater region (Islands of Japan and eastern Eurasian continent) will be important. In this context, we should emphasize that the suggested rotation of the Korean Peninsula with respect to the "stable" NCC took place in the Aptian time (~ 125 – 113 Ma) [11], but we do not know the geological significance of this event of rotation. We predict that the Yellow Sea opening related Korean rotation, if magnetically detectible at all, should be later than ~ 56 Ma.
6. The absolute testing of the hypothesis lies in ground truthing of the basaltic seafloor beneath the Yellow Sea by basement penetration drilling, but unusually thick sediments and sedimentary beds of up to ~ 20 km in both north and south Yellow Sea basins [14] would make it unpractical at present. Drilling at edges of these deep basins should be considered, and detailed geophysical (gravity, seismic and magnetic methods) surveys are required to choose target sites where basaltic crust can be potentially discovered. Finding of seafloor basaltic rocks is definitive proof of our hypothesis, but age data of these rocks can further certain constraints on the opening and seafloor spreading histories of the Yellow Sea.
7. The exact origin of the continental rifting, rift opening and seafloor spreading of the Yellow Sea is unknown and cannot be constrained at present. In fact, it is premature to attempt so until we work out temporal events around the greater Yellow Sea region recorded in rocks on landmasses from eastern China, the Korean Peninsula and islands of Japan as well as the ODP Legs 127 and 128 samples from the Sea of Japan. Given the youngest granitoids of ~ 56 Ma in the Russian Far East in the eastern active margin of the Eurasian continent, we predict that the opening of the Yellow Sea must be significantly later than ~ 56 Ma, most likely linked to the opening of the Sea of Japan in the time frame of ~ 27 Ma to 16 Ma (Fig. 1c).
8. The paleomagnetic data have been used to suggest that the landmass of Southwest Japan underwent clockwise rotation and thus must have separated from the Russian Far East [4]. However, this interpretation is inconsistent with the basement rocks having the affinity with the Cathaysia Block in South China (vs. the anticipated North China and Russian Far East; see [1]). In addition, much of the South Korea basement rocks correlate with those of South China [7-10] (Fig. 1b). All these observations require reconsideration of the inferences based on paleomagnetic data, and support the scenario of spatial association of Japanese landmasses with the landmasses of Koreas and eastern China prior to the opening of the Yellow Sea [see 2].
9. The exact timing of the continental rifting and rift opening of the Yellow Sea is yet to be determined, but its origin may be precursor of the opening of the Sea of Japan (since

~ 27 Ma?). The Yellow Sea may have stopped its seafloor spreading at ~ 16 Ma (?) at the arrival and subduction of the Philippine plate from south, which caused the Southwest Japan to drift towards southeast, also explaining its apparent clockwise rotation (Fig. 1c).

10. Integrated petrology, geochemistry, geochronology and paleomagnetic studies on Mesozoic rocks from eastern China, the Korean Peninsula, Islands of Japan, Russian Far East and basaltic rocks of the Sea of Japan (ODP samples) will be carried out to test the hypothesis and to resolve different interpretations towards verification of tectonic models of the northwestern Pacific in general and the origin and evolution of the Yellow Sea in particular. Elements of the work are currently under consideration by the second author as the continuation of [2] in collaboration with scientists from Korean, Japan and Russia.

Acknowledgments

This work was supported by NSFC grants (41130314, 91014003), Chinese Academy of Sciences Innovation grant (Y42217101L), grants from Qingdao National Laboratory for Marine Science and Technology (2015ASKJ03) and for Marine Geological process and Environment (U1606401). We thank Professors Shuguang Song and Zhidan Zhao for careful reading of earlier version of this paper

References

1. Niu YL, Liu Y, Xue QQ et al (2015) Exotic origin of the Chinese continental shelf: New insights into the tectonic evolution of the western Pacific and eastern China since the Mesozoic. Sci Bull 60: 1598-1616
2. Tang J, Xu WL, Niu YL, Wang F, Ge WC, Sorokin AA (2016) Geochronology and geochemistry of Late Cretaceous-Paleocene granitoids in Sikhote-Alin Orogenic Belt: Petrogenesis and implications for the oblique subduction of Paleo-Pacific plate. Lithos (in revision)
3. Maruyama S (1997) Paleogeographic maps of the Japanese Islands: Plate tectonic synthesis from 750 Ma to the present. Isl Arc 6: 121-142
4. Otofuji YI (1996) Large tectonic movement of the Japan Arc in late Cenozoic times inferred from paleomagnetism: Review and synthesis. Isl Arc 5: 229-249
5. Hall R (2002) Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations. J Asian Earth Sci 20: 353-431
6. Zhai MG, Guo JH, Liu WJ (2005) Neoarchean to paleoproterozoic continental evolution and tectonic history of the North China Craton: A review. J Asian Earth Sci 24: 547-561
7. Oh CW, Kim SW, Choi SG, Zhai MG, Guo JH, Krishnan S (2005) First finding of eclogite facies metamorphic event in South Korea and its correlation with the Dabie-Sulu collision belt in China. J Geol 113: 226-232
8. Zhai MG, Guo JH, Li Z, Chen DZ, Peng P, Li T, Hou QL, Fan QC (2007) Linking the Sulu UHP belt to the Korean Peninsula: Evidence from eclogite, Precambrian basement, and Paleozoic sedimentary basins. Gondwana Res 12: 388-403
9. Oh CW, Kusky T (2007) The late Permian to Triassic Hongseong-Odesan Collision Belt in South Korea, and its tectonic correlation with China and Japan. Int’l Geol Rev 49: 636-657
10. Hu B, Zhai MG, Li TS, Li Z, Peng P, Guo JH, Kusky TM (2012) Mesoproterozoic magmatic events in the eastern North China Craton and their tectonic implications:

Geochronological evidence from detrital zircons in the Shandong Peninsula and North Korea. Gondwana Res 22: 828-642.
11. Zhao XX, Coe RS, Chang KH, Park SO, Omarzai SK, Zhu RX, Zhou YX, Gilder S, Zheng Z (1999) Clockwise rotations recorded in Early Cretaceous rocks of South Korea: implications for tectonic affinity between the Korean Peninsula and North China. Geophys J Int’l 139: 447-463
12. Hao TY, Sun M, Liu JH, Yan XW, Choi S, Yao CL, Liu SH, Dai MG, Xu Y (2004) Deep structure and boundary belt position between Sino-Korean and Yangtze blocks in Yellow Sea. Earth Sci Front 11: 51-61 (In Chinese with English abstract)
13. Green DH, Falloon TJ (2015) Mantle-derived magmas: intraplate, hot-spots and mid-cean ridges. Sci Bull 60: 1873-1900
14. Wang YT, Wang LF, Zeng XH, Jin HF (2008) A preliminary analysis of the seismic velocity in the South Yellow Sea Basin and the North Yellow Sea Basin. Geophys Geochem Explor 32: 241-246 (In Chinese with English abstract)
15. Hao TY, Liu JH, Sun M, Choi S, Yan XW, Liu ZF (2003) Deep structure characteristics and geological evolution of the Yellow Sea and its adjacent region. Chin J Geophys: 46: 803-808 (In Chinese with English abstract)

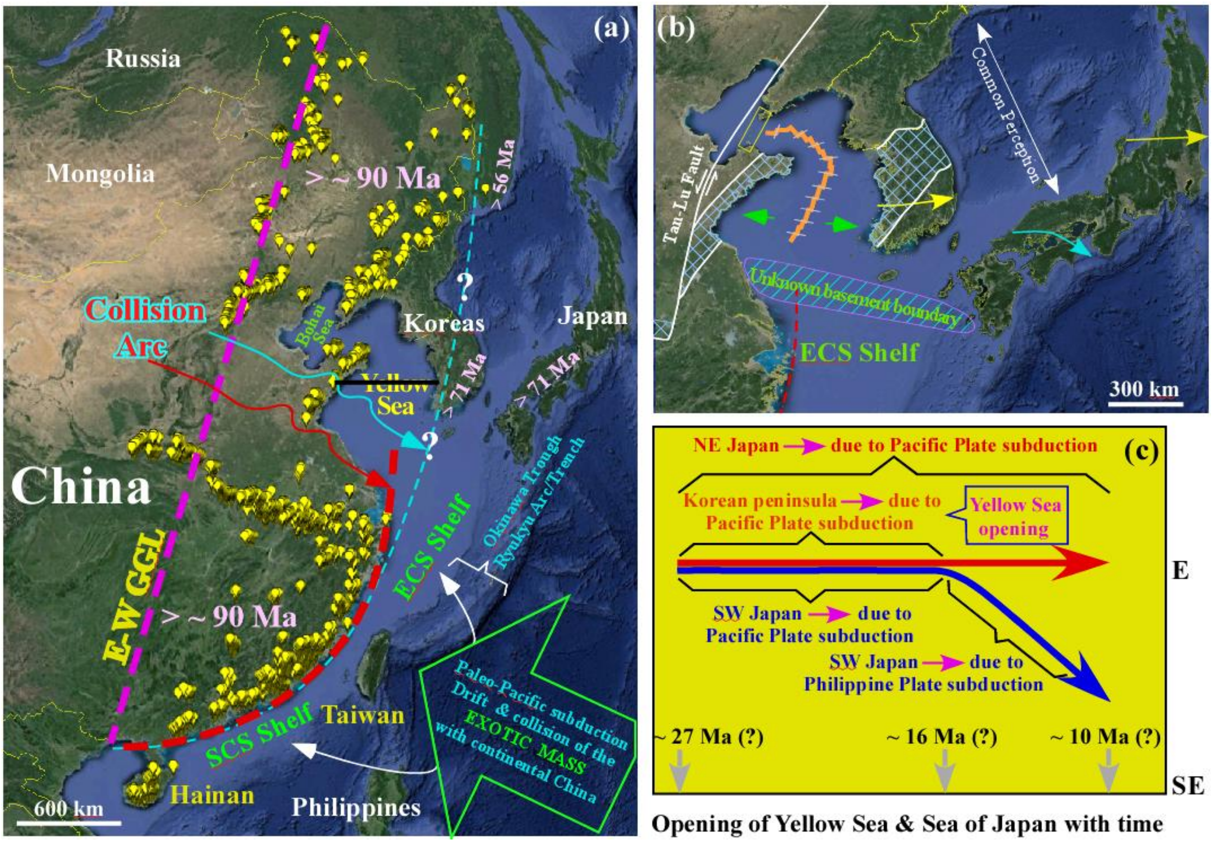

Fig. 1 **a** Modified from [1], showing the eastern continental China and adjacent lands and seas (Google Map, 2015) to illustrate the alien/exotic origin of the basement of the Chinese continental shelf beneath East China Sea (ECS) and South China Sea (SCS) [1]. No granitoids of < ~ 90 Ma are found in eastern China [1], but the younger granitoids in the Russian Far East (as young as ~ 56 Ma) and Korean Peninsula and Southwest Japan (as young as ~ 71 Ma) [2] offer an insight into the origin and nature of the Yellow Sea (YS). **b** Portion of **a** to show that the YS basement is not a continental shelf, but developed from continental rifting, rift opening, together with the opening of the Sea of Japan (SoJ), as a backarc basin in response to paleo-Pacific subduction. That is, the landmasses of Japan and the Korean Peninsula must have been

connected with eastern China before the rifting and opening. We predict that basaltic crust and failed rift (as indicated) should exist and be geophysically detected beneath the thickened sediments and sedimentary rocks. The Dabie-Sulu Orogenic belt indicated with mesh patterns correlate well with the same patterned terrane on the Korean Peninsula [2,7,9]. The opening of the Bohai Sea resulted from northward rift propagation of the YS, but its present geometry and basement morphology must be largely controlled by the active (once highly active) left-lateral Tan-Lu Fault. The yellow rectangle indicates that the Liaodong and Shandong peninsulas should remain largely connected as manifested by the chain of islets extending > 65 km from south to north. The double-arrowed white line across the SoJ is the common perception of the SoJ backarc opening. **c** Qualitative illustration of the opening of the YS and SoJ with time. The basaltic seafloor of the SoJ has been recognized (ODP Legs 127 and 128), but the absence of (or unknown yet) magnetic anomaly patterns [5] make it difficult to locate the spreading center, but we propose as follows: The opening of the YS and SoJ may have begun ~ 27 Ma (the ~ 27 Ma old basaltic seafloor rocks in the SoJ) in response to the paleo-Pacific subduction until ~ 10 Ma (the youngest seafloor basalt) as indicated by the arrowed red line and represented by the drift of the Northeast Japan in **b**. The seafloor spreading of the YS may have stopped at ~ 16 Ma when the Philippine Plate came to subduct northwestwards, causing the southeastward drift of Southwest Japan. That is, the Southwest Japan experienced eastward drift before ~ 16 Ma and then southeast drift, giving rise to the clock-wise rotation. This is consistent with our inference [2] and the fact that the basement of Southwest Japan shows affinity with the Cathaysia Block in South China [1].